MODELING AND DESIGN OF AN AUDIO AMPLIFIER SYSTEM

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MODELING AND DESIGN OF AN AUDIO AMPLIFIER SYSTEM

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in Electrical Engineering

By

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CERTIFICATE

This is to certify that the draft report/thesis titled "**Modeling and design of an Audio Amplifier System**", submitted to the National Institute of Technology, Rourkela by **Mr. Sarath Kanth (109ee0068) and Tejas Anishwar Mayor (109ee0281)** for the award of Bachelor of Technology in Electrical Engineering, is a bonafide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.
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In my opinion, the draft report/thesis is of standard required for the award of a Bachelor of Technology in Electrical Engineering.

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Prof. Susovon Samanta

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Ch. Sarath Kanth
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Dedicated to

Our Parents, and to each and every teacher, who taught us from alphabets to whatever till date. And to friends who have been there for us from genesis to apocalypse.

ABSTRACT

Sound amplification is required for variety of reasons. It has many applications in our day to day life. There are a variety of sound amplification techniques and each technique is employed depending on where and what kind of environment we are present. In this project of designing an audio amplifier system, first we studied the need for sound amplification and the basic block diagram of a sound system and its individual blocks. Microphones: their principle, different types, their working and equivalent SPICE models are followed. Thereafter, a brief study about the power amplifiers, their different classes and the PSPICE simulation models of all of them has been carried out. Class B power amplifier is then experimentally implemented to drive a speaker.

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ABBREVIATIONS AND ACRONYMS

SR System	-	Sound Reinforcement system
PA System	-	Public Address system
AM	-	Amplitude Modulation
TIM	-	Transient Inter Modulation
MEMS	-	Micro ElectroMechanical Systems
ECM	-	Electret Microphones
SPL	-	Sound Pressure Level
VCVS	-	Voltage Controlled Voltage Source

CHAPTER 1
INTRODUCTION

1.1 MOTIVATION

A sound system is the one that makes live or pre-recorded sounds louder and may also distribute those sounds to a larger or more distant audience. In some situations, a sound system is also used to enhance the sound of the sources on the stage, not only simply amplifying the sources unaltered but integrating them together. A sound system may be very complex, including hundreds of microphones, complex audio mixing and signal processing systems, tens of thousands of watts of amplification, and multiple loudspeaker arrays. Also a sound system can be as simple as a small public address system in a coffeehouse, consisting of a single microphone connected to a loudspeaker.

Here, in our project, we make an attempt to build one such PA system for domestic use.

1.3 APPLICATIONS

Important applications include public address systems, theatrical and concert sound reinforcement, and domestic sound systems such as a stereo or home-theatre system, Instrument amplifiers including guitar amplifiers.

1.4 BUILDING BLOCKS OF A SOUND SYSTEM

An Audio Amplification system is the combination of microphones, signal processors, amplifiers, and loudspeakers that makes live or pre-recorded sounds louder and may also transmit those sounds to a larger or more distant audience. The fundamental concepts related to the project include transducers, their principle, their application in microphones, power amplifiers, different classes of them and their characteristics etc.

More sophisticated sound systems are being developed nowadays which provide an amplified, high quality sound with perfect control over volume and frequency.

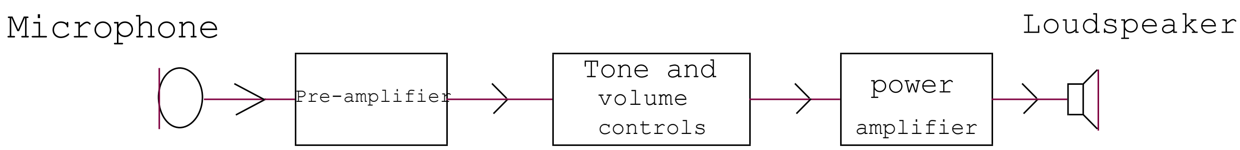


Figure.1.1 Block diagram of an audio amplifier system.

The power supply is connected to the pre-amplifier and power amplifier blocks.

- **Microphone -** a transducer which converts sound into voltage.
- **Pre-Amplifier** – amplifies or increases the strength of the small audio signal (voltage) coming from the microphone.
- **Tone and Volume Controls** – adjusts or allows us to set the nature of the audio signal. The tone control takes care of the balance of high and low frequencies. The volume control allows to adjust the strength of the signal.
- **Power Amplifier -** increases the strength (power) of the audio signal.
- **Loudspeaker -** a transducer which converts the audio signal to sound output.

CHAPTER 2
MICROPHONES

2.1 INTRODUCTION

Microphones are the transducers which convert sound to voltage. Sound signal exists as patterns of air pressure; the microphone changes this information into signal of electric current. A variety of techniques are used in building microphones.

2.2 DIFFERENT TYPES OF MICROPHONES

Two types of microphones are widely used:

* Dynamic type microphone   * Condenser type microphone

Dynamic type microphones:

Dynamic microphones are velocity sensitive. In these microphones, sound waves cause movement of thin metallic diaphragm and a coil attached to the diaphragm of wire.

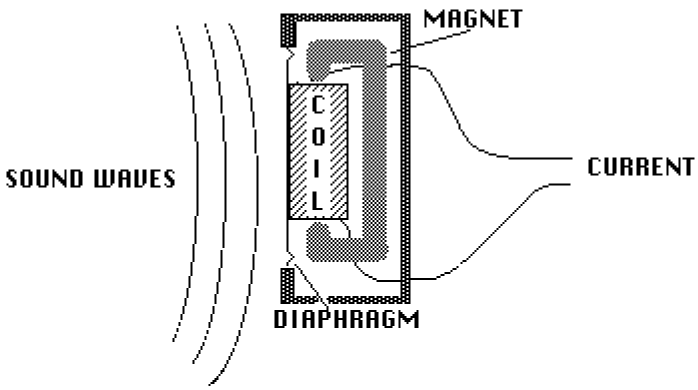


Figure.2.1 Diagram depicting working of dynamic microphones
(Reffered from “Modeling electret Condenser Microphones”, Texas Instruments Incorporated)

A magnet produces a magnetic field which surrounds the coil, and motion of the coil within this field causes current to flow. The current is produced by motion of the diaphragm and the amount of current is determined by speed of that motion. Wired microphones are examples of this kind.

Condenser type microphones:

In a condenser microphone, the diaphragm is mounted close to a rigid backplate. A battery is connected to both pieces of metal, which produces an electrical potential, or charge, between them.

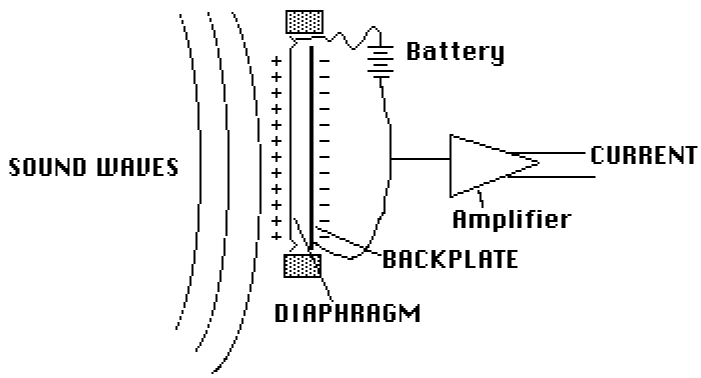


Figure.2.2. Diagram showing working of condenser microphones.
(Referred from "Modeling Electret Condenser Microphones", Texas Instruments Incorporated)

The amount of charge is determined by the voltage of the battery, the area of the diaphragm and backplate, and the distance between them. The amount of current is proportional to the **displacement** of the diaphragm, and is very small.

A common made design uses a material with a permanently imprinted charge on the diaphragm. Such a material is called an **electret** and is usually a kind of plastic. Phones, computers, hand free sets etc are examples of electret microphone using devices.

2.3 EQUATIONS (Referred from Texas instruments . Available at: http://www.ti.com)

The capacitance of a plane-parallel capacitor of plate area A and separation h is $C = 4\pi\kappa\varepsilon A/h$ F, where A is in m^2 and h is in m. The dielectric constant is κ, and $\varepsilon = 8.854 \times 10^{-12}$ F/m. Since the dielectric is air, we can take $\kappa = 1$. The charge on a capacitor charged to a voltage V is $Q = CV$.

If h varies, then $dC = -(4\pi\varepsilon A/h^2)dh = -(C/h)dh$. This means that the current will be $i = -(CV/h)(dh/dt)$.

If the diaphragm is stiffness-controlled, then $x = pA/s$, so $e = pVA/hs$ and the sensitivity $S = e/p = VA/hs$. The sensitivity is proportional to the bias voltage V and the diaphragm area A, and inversely proportional to the separation h and the stiffness s. Taking $A = 4\ cm^2$, $h = 0.01$ cm, and $s = 1 \times 10^8$dyne/cm, we find $S = 4*10^{-6}V$ V/μbar. If V = 2.4V, then S = 9.6μV/μbar. This happens to be a relatively typical value for a capacitor microphone. The capacitance of the microphone will be about 11.1nF, which will give a capacitive reactance of 9kΩ at 1 kHz, and 90kΩ at 100 Hz.

2.4 STANDARDIZATION

(Referred from John Eargle and Chris Foreman, "Audio Engineering for Sound Reinforcement", Hal Leonard Corporation, 2002.)

One of the most important standards is the "IEC 60268-4 Microphones,". A few of the most important specifications generally presented are: sensitivity, impedance, self-noise, the maximum permissible peak SPL, frequency response and directional characteristics.

Sensitivity

The sensitivity expresses the microphone's electric output when placed in a given sound field and a given sound pressure. The sound pressure is nominally 1 Pa (pascal is the unit for pressure). This is equivalent to a sound pressure level (SPL) of 94dB. The sensitivity is expressed either in volts/Pa (in practice 1/1000 volt, mV) or in dBV/Pa. ("dBV" is the same as "dB relative to 1 volt").

Example: 10 mV/Pa, *or* -40dBV/Pa, *or* -40dB re 1 volt/Pa. If the microphone is placed in an SPL of 114dB, the output is 10 times higher (equivalent to +20 dB), which yields 100mV or -20 dBV.

Impedance

The impedance is defined as the internal impedance measured between output terminals. As it is common to let one microphone directly feed more inputs, the minimum-permitted load impedance can be stated. Note that a heavy load on the output of a microphone normally reduces its ability to handle high sound pressure levels.

Self-noise

All microphones have a noise floor. The basic noise is simply caused by the presence of air around the microphone due to the movement of the air molecules. The noise specification is normally expressed as the so-called equivalent noise level. This indicates the sound pressure that will create the same voltage as the self-noise from the microphone produces.

The maximum permissible peak SPL

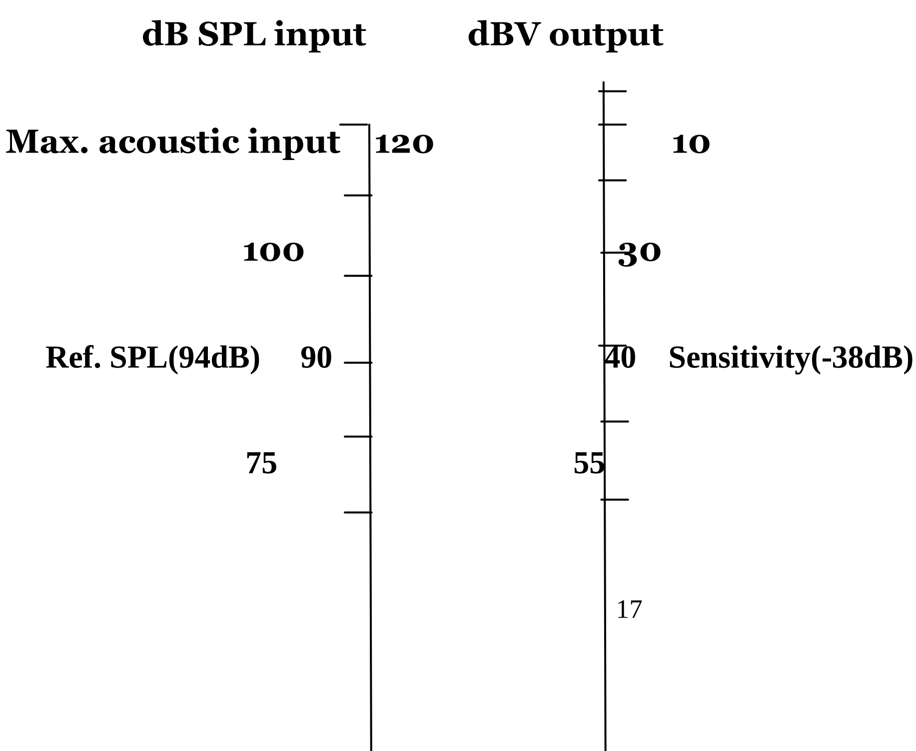
The maximum instantaneous sound pressure of a plane sound wave, specified by the manufacturer, that the microphone can tolerate without a permanent change of its performance characteristics, for any direction of sound incidence.

Frequency response

Often only the on-axis response is presented either as a curve or as a frequency range within specified limits. However, off-axis responses can be of great interest, especially regarding directional microphones.

Directional characteristics

The directional characteristics are expressed either by the characteristic pattern (omni, cardioid, figure eight, etc.) or by a set of curves. The curves are always interesting, and again the scale is important.



60 70

—— ——

50 —— 80——

—— ——

40 90

—— ——

Figure 2.3.1 : Voltage output level for analog microphone

Most analog electret and MEMS microphones have sensitivity between –46 dBV and 35dBv (5.0 mV/Pa to 17.8 mV/Pa). This level is a good compromise between the noise floor and the maximum acoustic input—which is typically about 120 dB SPL.

2.6 ELECTRET MICROPHONES

An electret material is one that has been given a quasi-permanent electrostatic charge through a process that involves heating the material under a strong electric field. When the heat and electric field are removed, the material maintains its own electrostatic charge. The high internal resistance of the material ensures that the charge can be held between twenty and thirty years, which is why the charge is typically dubbed “quasi permanent.”.

2.7 PSPICE MODEL OF MICROPHONE

System Input

To make conversions simple a sound pressure of 1 pascal (Pa), treated as an rms measurement, is represented by a 1 V_{rms} signal.

A microphone’s sensitivity specification dictates what signal output level, in V_{rms}, should be expected for a given sound pressure input in Pa. A microphone with 0 dB of sensitivity is defined to produce a 1 V_{rms} output, given a 1 Pa sound pressure input. The microphone being modeled has a sensitivity of –35 dB. Therefore, a sound pressure input of 1 Pa will cause a 17.78 mV_{rms} output on the microphone.

$$\mathbf{-35 = -20 \log(x/1V_{rms}) \Rightarrow x = 1V_{rms} * 10^{(-35/20)} \Rightarrow x = 17.78mV_{rms}}$$

To match the model's output to these calculations, you must first determine the JFET amplifier's gain. By running an ac transfer function sweep of the JFET, the gain of this JFET is found to be 8.81 dB.

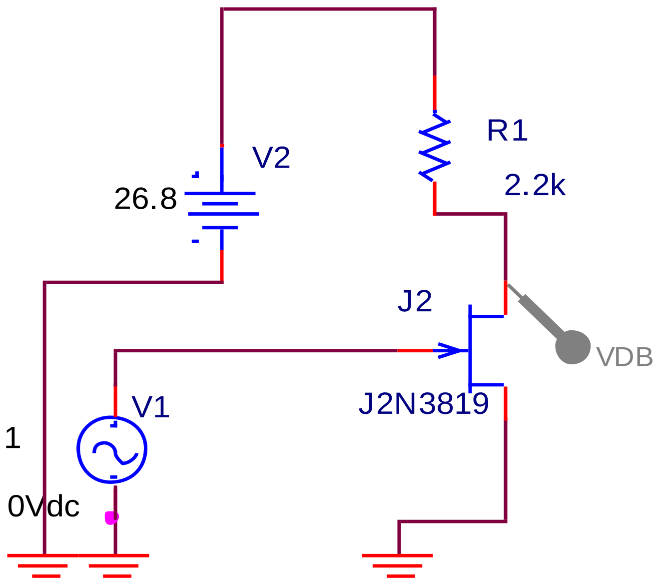


Figure 2.7.1: Microphone Gain Test

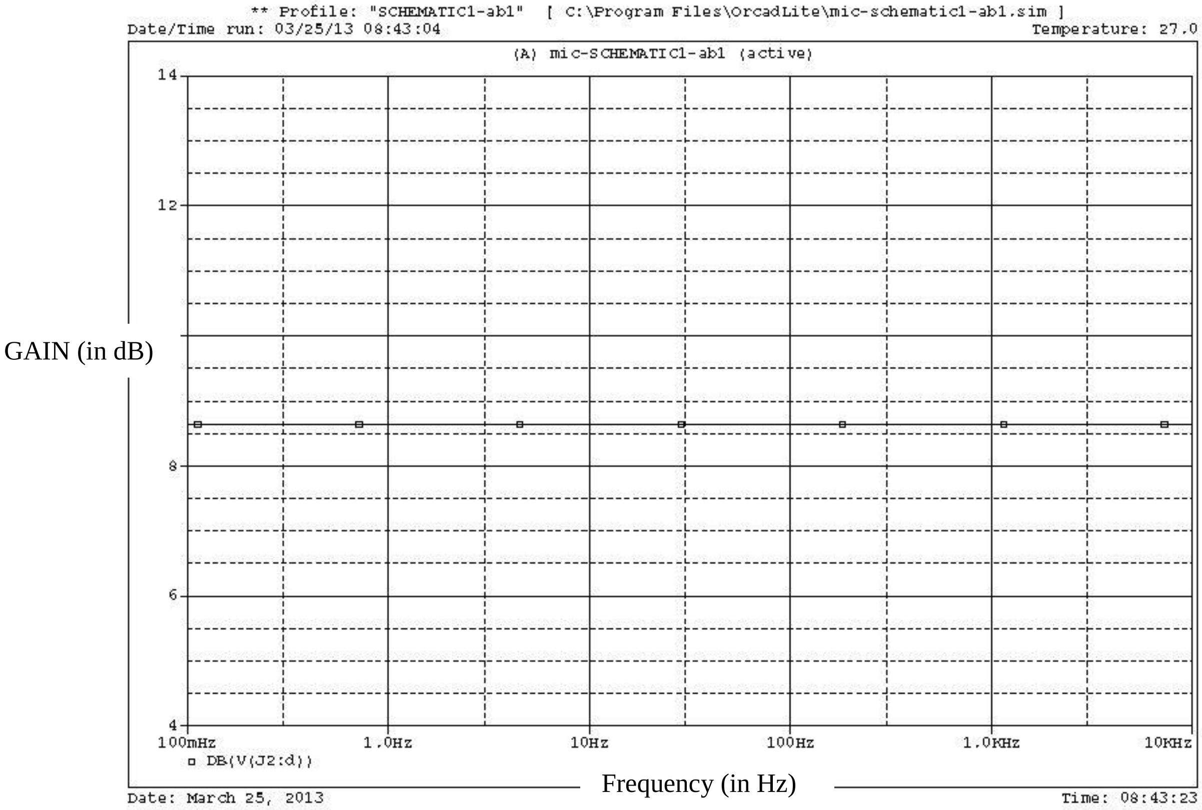


Figure 2.7.2 Microphone Gain

To set the model's sensitivity to –35 dB, simply attenuate the input to the JFET by adding a voltage-controlled voltage source (VCVS) in series with the JFET gate. To correctly set the sensitivity, you must cancel out the gain of the JFET. Therefore, to get the needed attenuation, subtract the JFET gain from the sensitivity specification.

VCVS amplification = Sensitivity – Gain of JFET

$$= -35\text{dB} - 8.81\text{dB} = -43.81\text{dB}$$

VCVS amplification = $10^{(-43.81/20)} = 0.0065$V

Run an ac transfer sweep with the updated model to test the results.

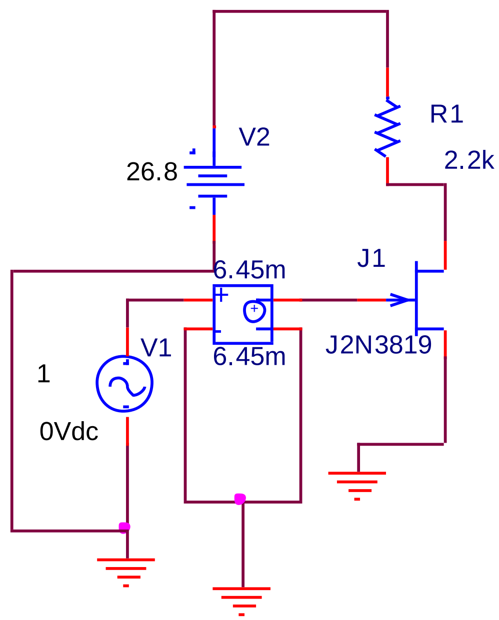


Figure 2.7.3 Sensitivity Test

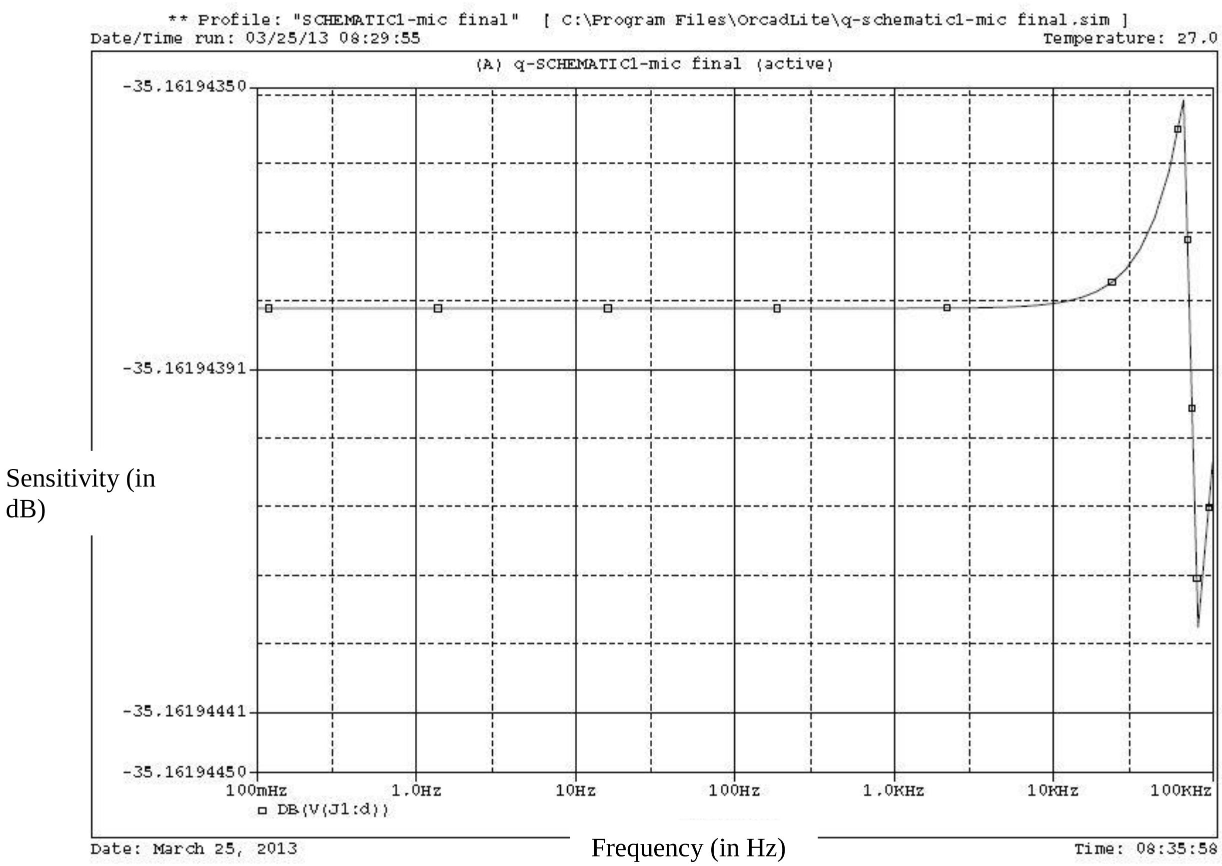


Figure 2.7.4 Sensitivity of the Microphone

Chapter 3
POWER AMPLIFIERS

3.1 INTRODUCTION

An Amplifier receives a signal from some pickup transducer or other input source and provides a larger version of the signal to some output device or to another amplifier stage. An input transducer signal is generally small (a few milli volts from a cassette or CD input or a few micro volts from antenna) and needs to be amplified sufficiently to operate an output device (speaker or other power handling device). Large-signal or power amplifiers increase circuit's power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedance matching to the output device. One method used to categorize amplifiers is by class. Basically, amplifier classes represent the amount the output signal varies over one cycle of operation for a full cycle of input signal.

3.2 DIFFERENT CLASSES OF AMPLIFIERS

Class A: The output signal varies for full 360° of the cycle. This requires the Q-point to be biased at a level so that at least half the signal swing of the output may vary up anddown without going to a high-enough voltage to be limited by the supply voltage level or too low toapproach the lower supply level, or 0 V in this description.

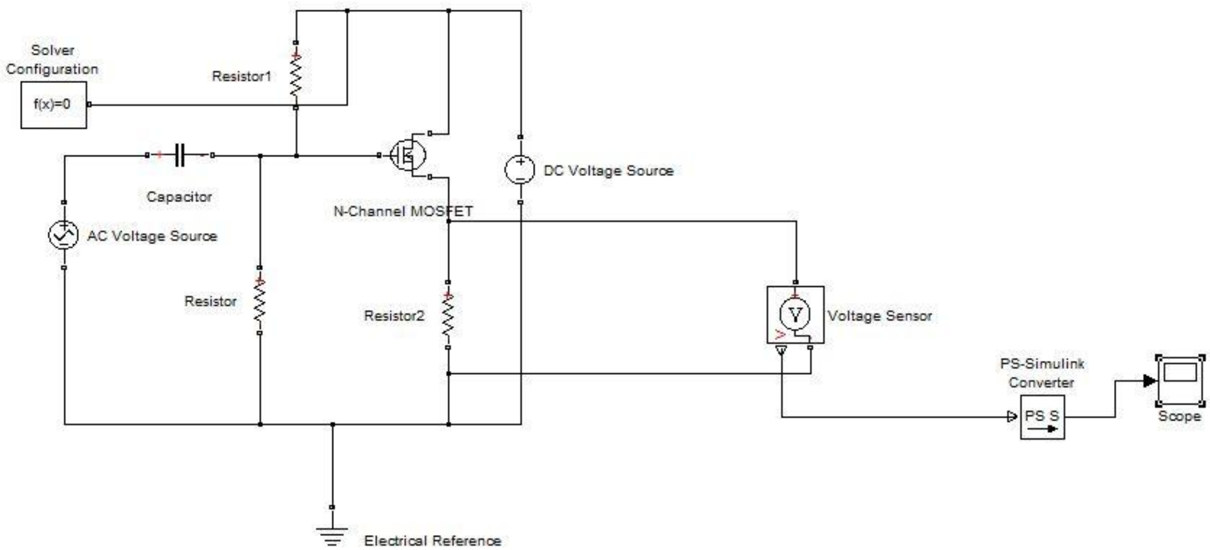


Figure 3.1: CLASS A amplifier circuit.

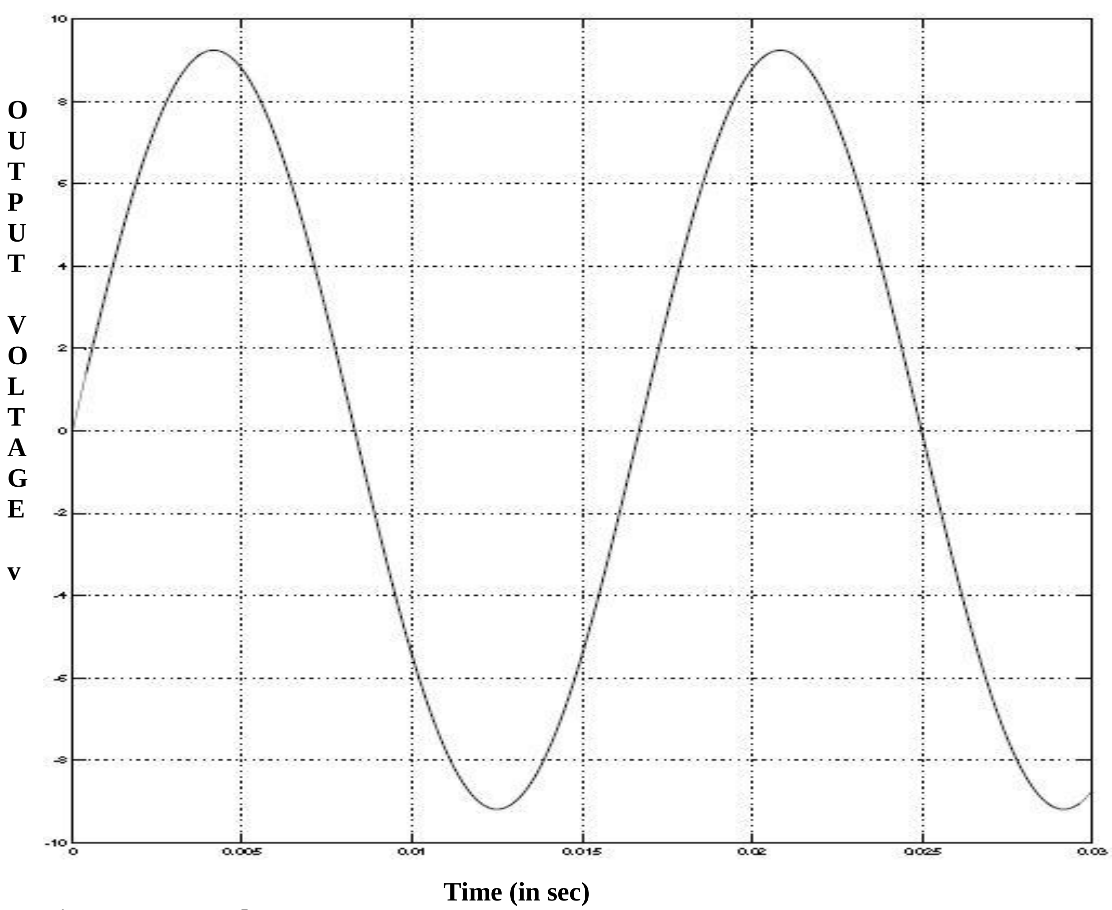


Figure 3.1.2 Class A output waverorm

Class B: A class B circuit provides an output signal varying over one-half '.-: input signal cycle, or for 180° of signal, as shown. The dc bias point for class B is therefore at 0 V, with the output then varying from this bias point for a half-cycle. Obviously, the output is not a faithfulreproduction of the input if only one half-cycle is present. Two class B operations-one to provide output on the positive output half-cycle and another to provide operation on the negative-output halfcycle are necessary. The combined half-cycles then provide an output for a full 360° of operation. This type of connection is referred to as push-pull operation, which is discussed later in this chapter.

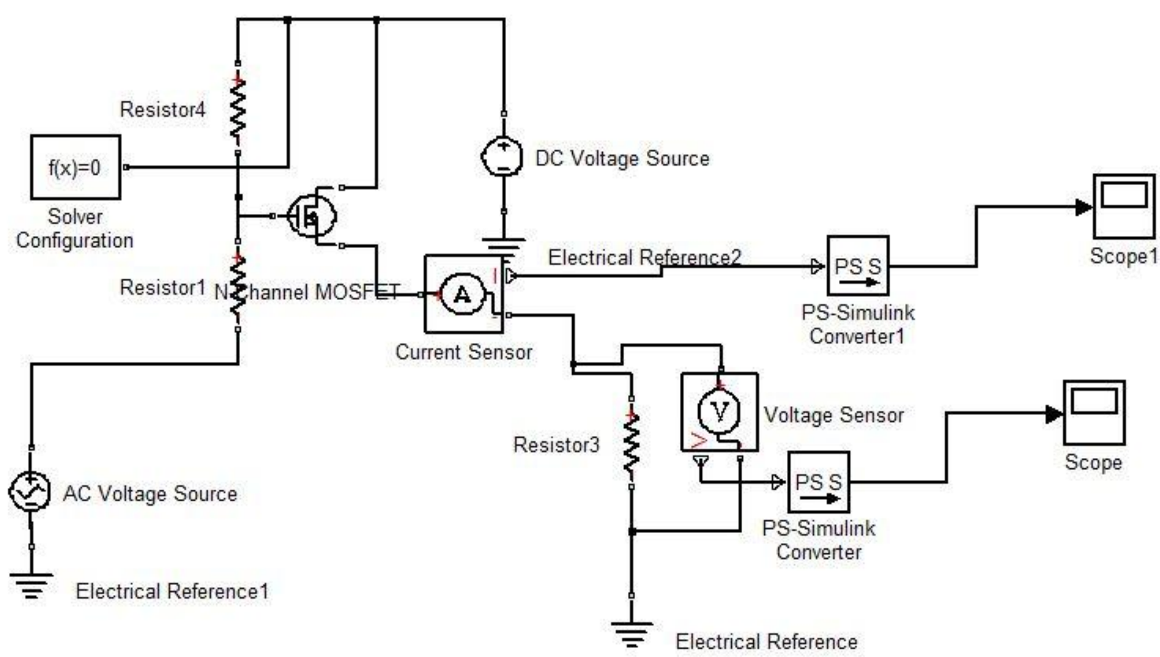


Figure 3.2: CLASS B AMPLIFIER CIRCUIT

Note that class B operation by itself creates a very distorted output signal since reproduction of the input takes place for only 180° of the output signal swing.

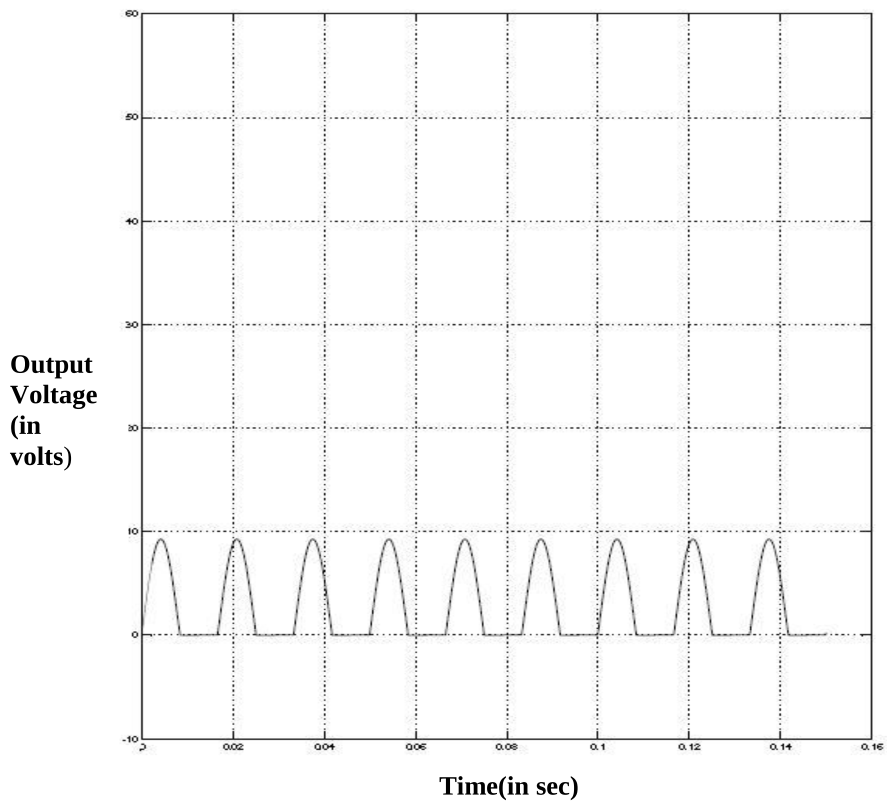


Figure 3.2.1 Class B output waveform

Class B push-pull: An amplifier may be biased at a dc level above the zero base current level of class B and above one-half the supply voltage level of class A; this bias condition is class B. Class B operation requires a push-pull connection to achieve a full output cycle, but the dc bias level is usually closer to the zero base current level for better power efficiency, as described shortly. For class B operation, the output signal swing occurs between 1800 and 3600.

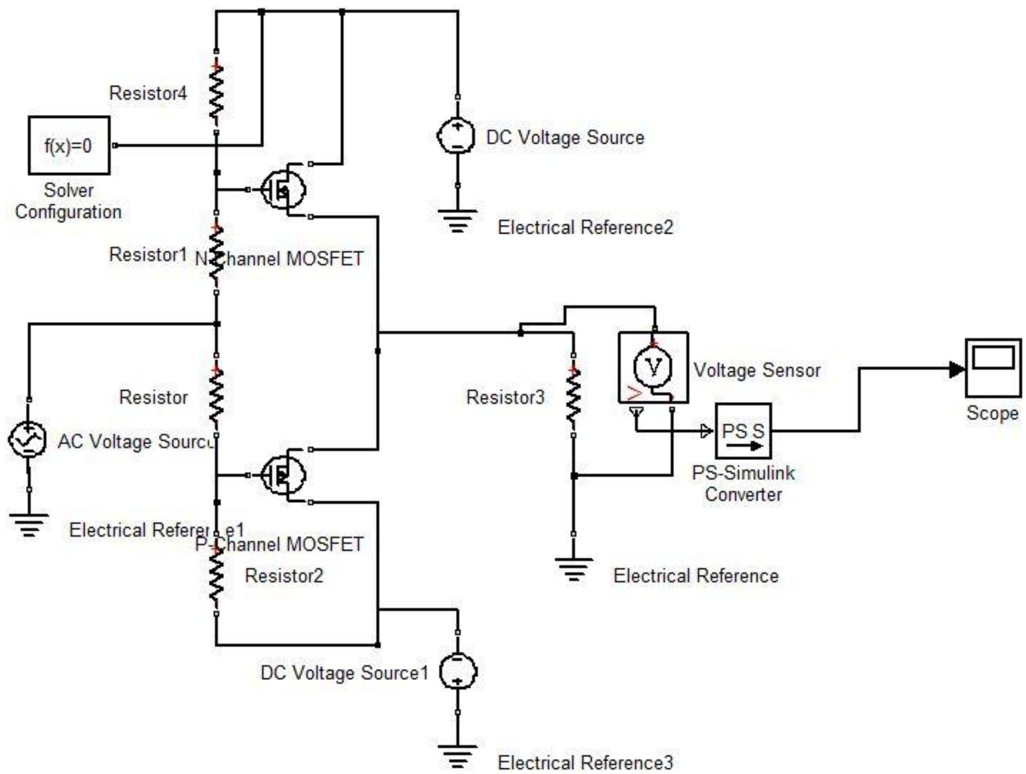


Figure 3.3: CLASS B push-pull amplifier circuit.

Class D: This operating class is a form of amplifier operation using pulse (digital) signals, which are on for a short interval and off for a longer interval. Using digital techniques makes it possible to obtain a signal that varies over the full cycle (using sample-and-hold circuitry) to recreate the output from many pieces of input signal. The major advantage of class D operation is that the amplifier is on (using power) only for short intervals and the overall efficiency can practically be very high, as described next.

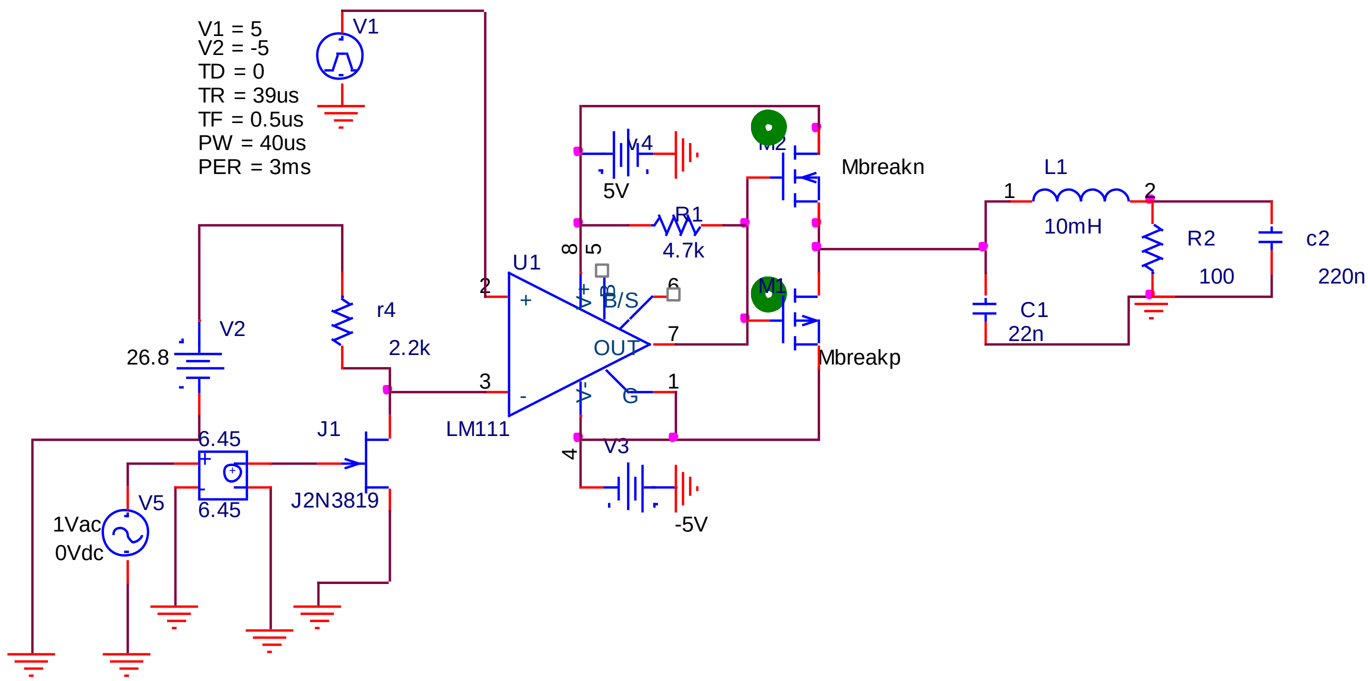


Figure 3.4: Class D Power Amplifier Circuit

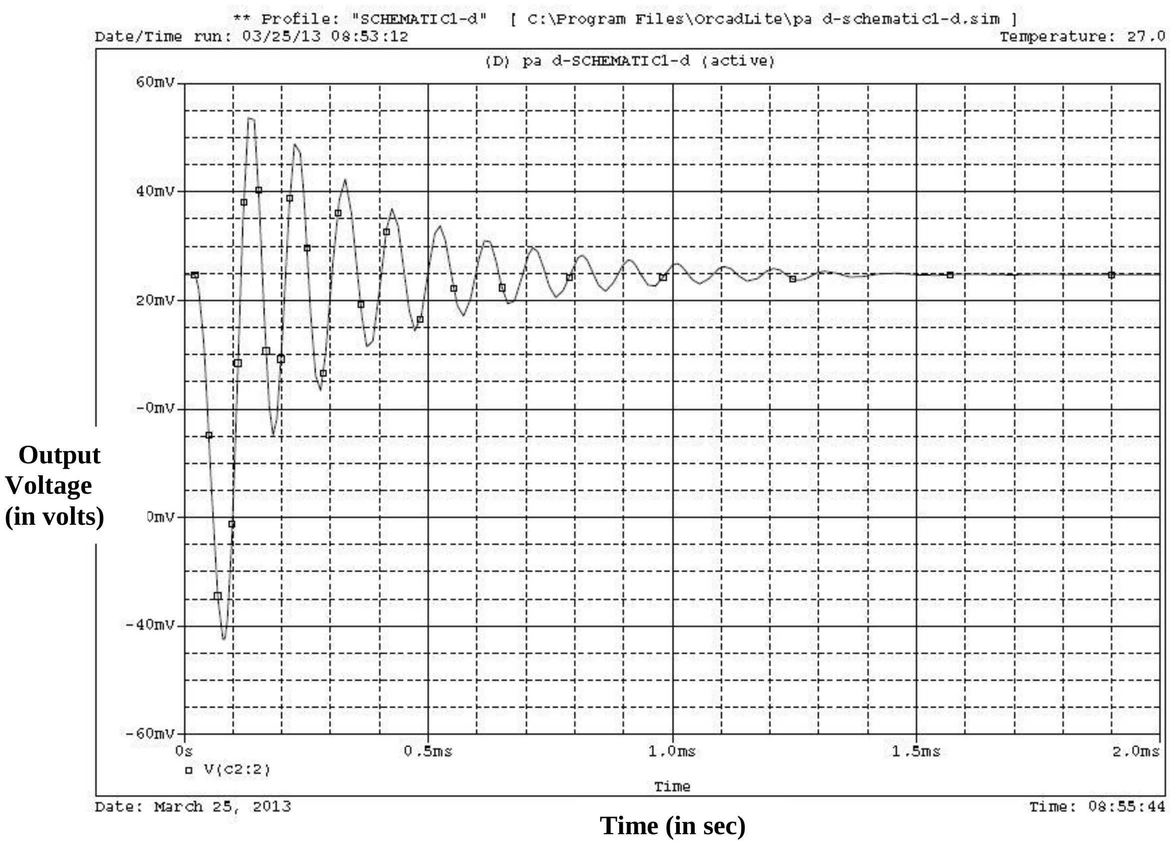


Figure 3.4.2 Class D output

CHAPTER 4

PRACTICAL IMPLEMENTATION OF THE DESIRED WORK

4.1 CLASS A AMPLIFIER: SPECIFICATIONS

50 WATTS

COMPONENT PARAMETERS:

$R_1 = 22k\Omega$ $R_2 = 56K\Omega$

$R_{load} = 8\Omega$ $C_{in} = 2.2F$

DEVICE SPECIFICATIONS:

MOSFET : IRF530

4.2 CLASS B AMPLIFIER: SPECIFICATIONS

COMPONENT PARAMETERS:

$R_1 = 22k\Omega$ $R_2 = 1.5K\Omega$

$R_3 = 22K\Omega$ $R_4 = 1.5K\Omega$

$R_{load} = 8\Omega$

DEVICE SPECIFICATIONS:

IRF 9530 P-channel

IRF 530 N-channel

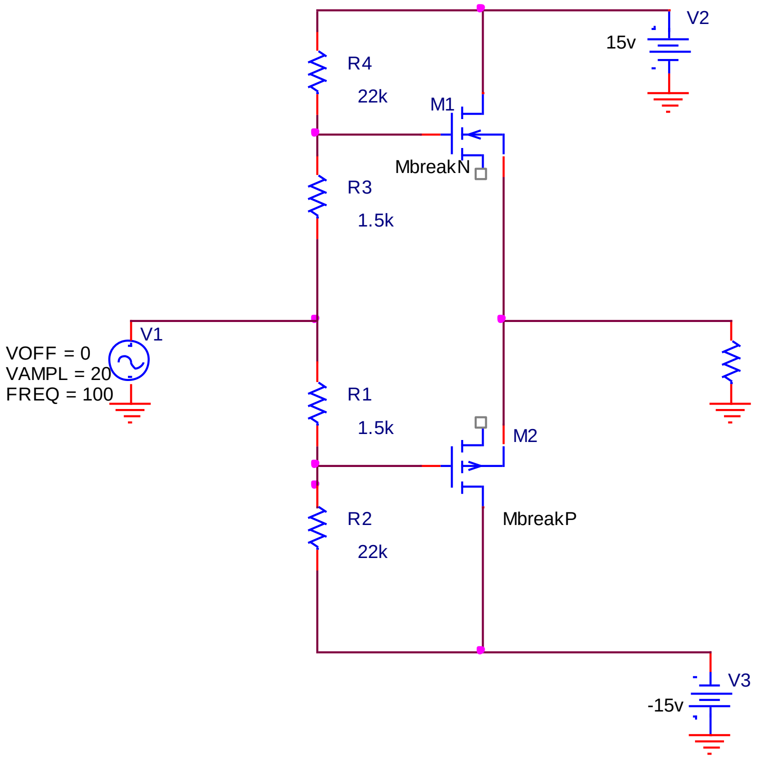


Figure 4.2.1 Circuit for calculation of power gain of class B

$V_{in} = 16.6V_{p\text{-}p}$
$V_{out} = 11.4\ V_{p\text{-}p}$

$V_{out\ rms} = 5.7*0.707 = 4.03V$

$P_l = 4.03^2/8 = 2.03W$

$A_p = A_i * A_v$

$Z_{in} = R_1 \parallel R_2 \| R_3 \| R_4$
$= (1.5 * 22)/ (2* 23.5) = 0.702k\Omega$

$I_{in} = V_{in} / Z_{in} = (8.3*0.707) / (0.702*10^3) = 8.36mA$

$I_{out} = V_{out} / R_l = 4.03/8 = 0.5A$

$A_i = 0.5/ 8.36mA = 60$

$A_v = 11.4/16.6 = 0.686$

Therefore, $A_p = 60 * 0.686 = 41.20$

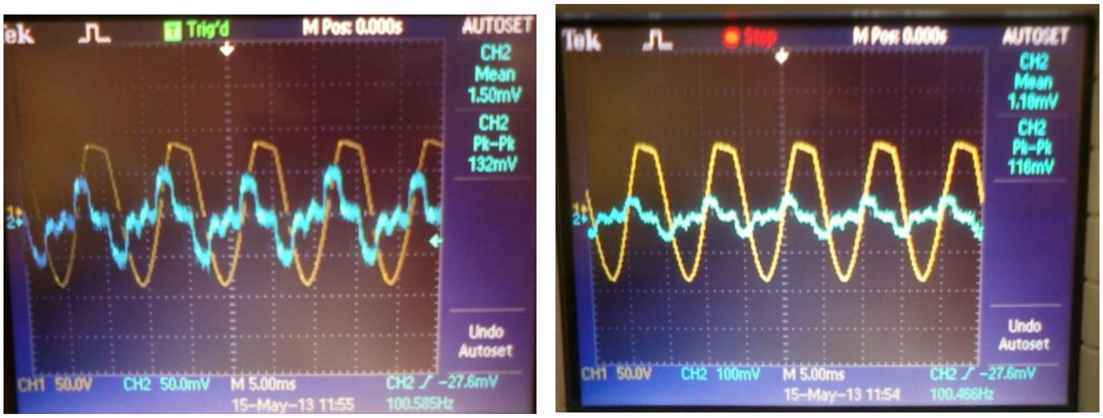


Figure 4.2 Output and input waveforms together

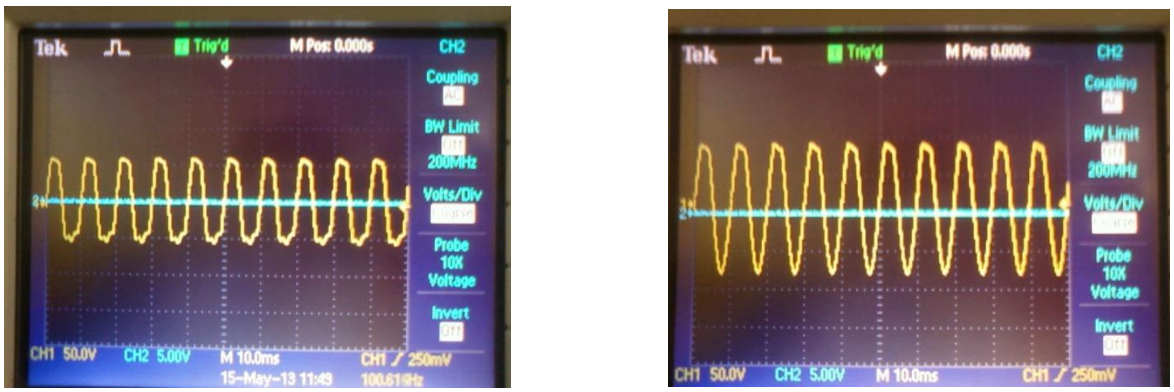


Figure 4.2 Output and Input waveforms separately of Class B amplifier

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSION

The Audio amplifier systems that are available in the market are known and the feasibility of these systems is analysed. The internal structure of the electret microphone, JFET used in it to buffer the small signal current produced and the dynamic equations of electret microphones are studied. Different classes of amplifiers are studied and the equivalent PSPICE models are simulated. Class A, Class B amplifiers are modeled and the results are matched with the simulated models successfully.

5.2 FUTURE WORK

While this project was successful in designing and implementing a fully functional Class B audio amplifier there are many additional areas that can be explored to complement the completed more efficient Class D audio amplifier. The focus of this project was to develop an amplifier to drive an 8Ω load. However, a working amplifier is a component that can be used in many different products, from guitar amplifiers to home theater receivers.

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